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AUTOMATED COCKPIT TECHNOLOGIES:
IMPLICATIONS FOR AIR MOBILITY COMMAND AIRCREWS

GRADUATE RESEARCH PROJECT

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GRADUATE RESEARCH PROJECT

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Table of Contents

Page

List of Figures

List of Tables

Abstract

The Air Force has purchased its first new generation of airlift aircraft with the acquisition of the C-17. More than just replacing the C-141 as the workhorse of the Air Force, the C-17 has also replaced part of the crew with inertial navigation systems, computers, and automation. The reliance on the automation of the C-17 demands a smooth interface between crew and automation, the crew must stay informed of the progress of the systems, and remain prepared to assume manual control should the automation fail. To accomplish this, the automation must be designed for ease of use and the crew must be trained to work in harmony with each other and the automation.

Each aircraft manufacturer has a particular philosophy about how its aircraft are automated, and each aircraft operator has a philosophy about operating those aircraft. An understanding of these philosophies and the knowledge of problems associated with automation are valuable tools for pilots. This paper will discuss those philosophies, including the philosophies of the design and operation of the C-17.

Fortunately, civilian aviation has had over ten years of experience dealing with the many intricacies of these highly automated aircraft. Pilot reports and academic research have identified specific problems, or pitfalls associated with automated aircraft. This paper presents pitfalls to be avoided by Air Force operators.

AUTOMATED COCKPIT TECHNOLOGIES:

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I. Introduction

General Issue

In no endeavor has technology been brought to bear more effectively than in the aviation profession, and no profession has more effectively stimulated the advance of technology. In less than one hundred years we have moved from the first flight of the Wright brothers to transporting hundreds of people and tons of cargo in aircraft utilizing the latest advances of computer technology. In the course of this development process, we have learned how to automate nearly the entire process of flying. But have we gone too far? When does the pilot become a redundant component to the automation?

The civilian airline industry led the way with the two-pilot cockpit concept. The latest aircraft from Boeing, McDonnell Douglas, and Airbus are all highly automated, two-person cockpits. Many airlines are currently flying these aircraft with great success and the military has just begun operating its first advanced technology heavy airlift aircraft. But how much of what civilian aviation has learned will adapt to the inherently distinct missions of military aviation?

Problem Statement

Recently, the Air Force published operating policies on the use of automation in Multi-Command Instruction (MCI) 11-217, Volume 5. This document provides excellent information to the crews flying the C-17, but there is additional information available from research and civilian airline operations to further benefit aircrew flying highly automated aircraft. This paper consolidates that information to further an understanding toward operating the C-17 and future highly automated aircraft.

Research Objective

The objective of this paper is to discuss the design philosophies of automated aircraft. Philosophies are addressed from the design perspective as well as from the view of the companies operating highly automated aircraft. This paper includes a discussion of unanticipated dangers, or pitfalls, associated with automated aircraft. Understanding pitfalls previously identified by accident/incident investigation and research will prove a valuable asset to any operator. A final objective of this paper is to recommend operating policies for inclusion to Air Force operating instructions.

Research Questions

This paper addresses the following research questions:

1. How can the Air Force improve operating philosophies provided to C-17 crews?

To fully develop this answer, the following questions will be addressed:

2. What is automation philosophy and why is it important?

3. What are the philosophies of aircraft designers?

4. What are the philosophies of airline companies?

5. What are some of the potential pitfalls associated with automated aircraft today?

This paper addresses these questions through a discussion about what a philosophy is, and how it relates with the policies and procedures of design and operations. Individual aircraft manufacturer and airline philosophies are presented with a discussion about some of the pitfalls encountered in operating these highly automated aircraft. Included in this discussion will be the design and implementation of automation in the C-17. This paper concludes with recommendations to existing Air Force policies about operating the C-17.

II. Automation

Automation is a technology that works best in predetermined situations such as those which can be planned and programmed ahead of time. Technology does not always provide quick and easy flexibility when the external situation changes. Christopher Wickens, a noted industrial psychologist, says automation should be used to perform functions that the human operator either cannot perform, performs poorly, or in which the human operator shows limitations (Wickens, 1992, p. 531).

The introduction of automation to the cockpit of current aircraft has greatly benefited aviation. Today's pilot has available at his fingertips more information than could be carried in even the largest map case. However, without proper guidance, this information is of little use, and used inappropriately it could be disastrous. Degani and Wiener (1994) point out that to operate a complex system successfully, the human-machine system must be supported by an organizational infrastructure of operating concepts, rules and guidelines. There cannot be a procedure for everything, and the time will come when the operators of a complex system face a unique situation for which there is no procedure. It is at this point that we recognize the reason for keeping humans in the system, since automation, with all its advantages, is merely a set of coded procedures executed by the machine. Nowhere is there a more dramatic example of human ingenuity than the United Airlines DC-10 that crashed in Sioux City on July 19, 1989. Government investigators determined that the plane crashed because a metal fan disk in the tail engine broke up in flight and metal shards severed all the hydraulic lines that controlled the plane's steering system . When the pilot regained aircraft control he turned to the flight engineer and asked what was the procedure. The engineer's reply was: "There is none" (Degani, 1994). Only human ingenuity, good crew resource management skills, and a little luck saved 184 of the 296 people on board when the plane crashed on a runway in Iowa. Attachment 1 contains a synopsis of additional aircraft incidents/accidents that have been attributed to aircraft automation.

Philosophy, Policies and Procedures

A philosophy is a system of beliefs or a doctrine that includes the critical study of the basic principles for guidance in practical affairs (Palmer, et al., 1995). Automation philosophy can be defined as the over-arching view of how automation should be utilized in an aircraft. There is a philosophy toward the development of the system itself as well as a philosophy toward the operation of that system. Company philosophy is largely influenced by the individual philosophies of the top decision makers. They should be complementary to each other, but sometimes they are not. An airline manager may not be able to clearly state his airline's philosophy, but a philosophy does exist and can be inferred from procedures, policies, training, and punitive actions (Degani and Wiener, 1994, p. 49).

The emergence of flight deck automation as an operational problem has generated an interest in the philosophy of operations, partly due to lack of agreement about how and when automatic features are to be used, and who makes the decision, the company or the pilot in command. The unlimited capability of today's Flight Management Systems (FMS) to operate between any range of fully automated to manual control has convinced some airlines that it is necessary to formally state a company philosophy of operational utilization of automation. However, this philosophy must allow a pilot the freedom to improvise, as no philosophy can address every issue a pilot will encounter.

Policies are plans, or courses of action, that will dictate what the company expects on the line. Policies are developed to adhere to the primary operating philosophy. Policies are broad specifications of the manner in which management expects operations to be performed (training, flying, exercise of authority, personal conduct, etc.) (Degani and Wiener, 1994). Procedures, then, are more exact actions or methods used to carry out the stated philosophy of the company. Procedures should be designed to be as consistent as possible with the policies (which are consistent with the philosophy). This structure is depicted in Figure 2. Procedures will dictate specific actions to the pilots, but an understanding of the designer's philosophy behind the development of the automation will provide the pilot with the flexibility to confront those situations which are not addressed by procedure.

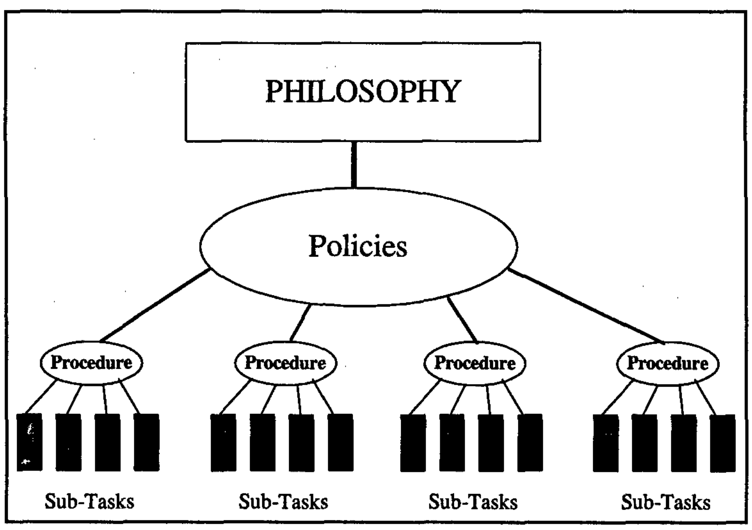

Figure 1: The Three Ps (Degani and Wiener, 1994, p. 50)

Standard operating procedures (SOPs) are sets of procedures that, apart from being merely specifications of tasks, also serve to provide a common ground for a flight crew which, at times may be totally unfamiliar with each other's experience and technical capabilities (Degani and Wiener, 1994, p. 48). The airline industry is a strong proponent of SOPs. Airlines attempt to attain a level of standardization such that if a cockpit crewmember were to be replaced in mid-flight the operation would continue safely and smoothly. While SOPs promote uniformity of operations among large groups, they do so at the risk of reducing the role of the human operator to a lower level (Degani and Wiener, 1994). When systems operators are reduced to the role of systems monitors, complacency is often mentioned as a potential negative effect (Parasuraman, Molloy, and Singh, 1993). The system designer must recognize this, and design systems to exploit the most valuable asset in the system, the operator. Further, it is important for management to provide consistent and technically correct procedures, which in turn will ensure the economical utilization of both humans and equipment, and the safe conduct of flight. Any procedure, even the best one, can not be error proof. The role of airline management is to provide the best possible baseline for its crews, and then train and standardize to this baseline (Degani and Wiener, 1994, p. 65). No procedure is a substitute for an intelligent operator.

Human-Centered Aviation

One design philosophy that is gaining momentum in the aviation industry is Human-Centered Aviation. This philosophy, developed by Dr. Charles E. Billings of Ohio State University, recognizes that today's aircraft are not always designed to facilitate effective cooperation between the pilot and the machine (Billings, 1996). Until now, the philosophy of adding automation to the cockpit seems to be: if it can be automated, do it. According to Dr. Billings, over time this has had the effect of making the flight crew more peripheral to the actual operation of the aircraft (see Figure 2).

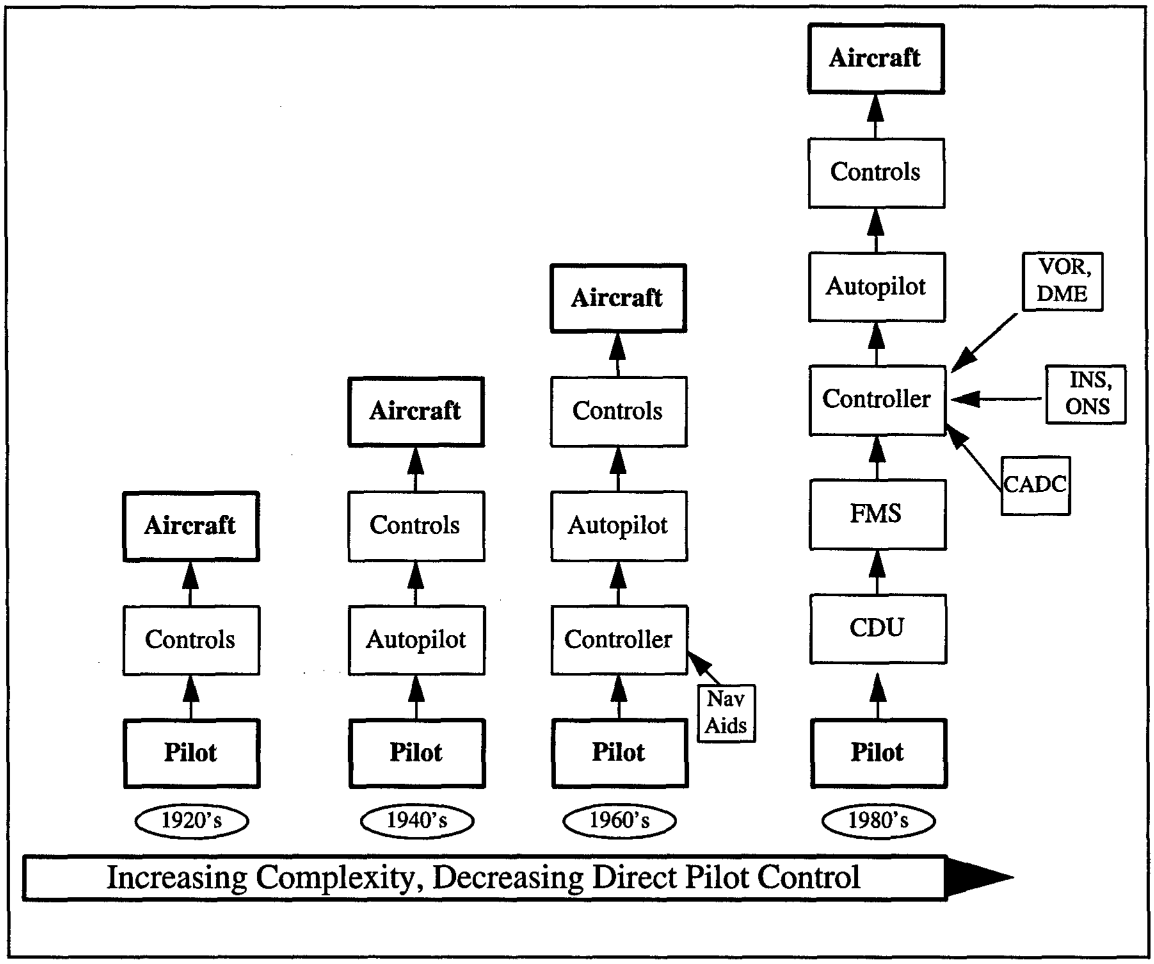

Figure 2: Trends in Aircraft Automation (Billings, 1996, p. 6)

Dr. Billings notes that the progress of automation technology will continue to accelerate during the next decade. For this reason, it is essential that designers have a clear understanding of the effects of these systems on the human operator. The concept of "human-centered" automation is an attempt to design the system beginning with the human and developing tools and artifacts specifically to *complement* the pilot's capabilities.

No one questions the necessity for operator involvement in flight operations, but Dr. Billings contends that too little involvement will cause the pilot to lose situational awareness, and when required to assume manual control due to a failure in the automation, the pilot will not be able to respond in either an appropriate or timely manner. The current pattern of aircraft design is one in which the pilots either do not understand what the automation is doing or do not receive adequate feedback from the automated systems (Hughes, et. al, Jan, 1995, p. 52). Billings recommends system designers incorporate an active role for the pilot. This may involve any or all of complete, active control, decision-making toward allocation of resources, or evaluation of alternatives.

Other principle features of Human-Centered Aviation include:

- Keeping the pilots informed of automated actions
- Automated systems must be predictable
- Automated systems must be able to monitor the human operator

Dr. Billings sums up his discussion about human-centered automation by pointing out that although humans are far from perfect sensors, decision-makers and controllers, they possess three invaluable attributes. They are excellent detectors of signals in the midst of noise, they can reason effectively in the face of uncertainty, and they are capable of abstraction and conceptual organization (Billings, 1996, p. 13). Humans therefore provide to the aviation system a degree of flexibility that cannot now, and may never, be attained by computers.

III. Designers' Philosophy

Every aircraft designer has a different overriding philosophy concerning what can and should be automated. That philosophy is the result of a combination of higher level corporate guidance, how previously produced aircraft were automated, and the availability of technology to automate the desired function, as well as access to that technology. As in all business decisions, cost is always a major factor.

The FAA recently commissioned a Human Factors (HF) Team to report on interfaces between flightcrews and automated aircraft. The study, Interfaces Between Flightcrews and Modern Flight Deck Systems, is the result of observations and interviews with aircraft manufacturers, airline representatives, pilots' associations, and researchers from various aviation organizations (Abbott, et al, 1996). The Human Factors team recommends areas that should be addressed by the FAA and gives guidance to aircraft designers and operators to improve man-machine interface.

Management of Automation

The Human Factors team report expressed a concern about two major issues regarding automation; pilot understanding of the automation and differing pilot decisions about the appropriate automation level to use.

First, the team observed and was briefed by pilots themselves that too often pilots are surprised by the actions of automation in their aircraft. Flightcrews often are faced with questions such as, "Why did it do that?," "What is it doing now?" and "What will it do next?" The team found that some of the automation surprises reflect an incomplete understanding of either the automation's capabilities and limitations, its intended use or the aircraft's display annunciation (Abbott, 1996, p. 33).

The HF team found differing views regarding training for automation. Some views held that flightcrews should be relieved of the burden of fully understanding system operation or the system's underlying design philosophy (Abott, 1996, p.33). This view would ultimately lead to a training philosophy in which flightcrews are trained to respond primarily in a rote manner (i.e., standard operating procedures). While it is recognized that the use of standard operating procedures (SOPs) is an effective strategy for managing error, the report states:

> It is important for flightcrews to understand the principles and assumptions embodied in the automation design that affect safe operational use, especially where these principles and assumptions may differ from those of the flightcrew. In the absence of this understanding, flightcrews are likely to substitute their own model of how the automation works, based on their observations and assumptions of automation behavior". (Abbott, 1996, p. 34)

Instances where the flightcrew's model is incomplete or incorrect could lead to confusion and increase the potential for error. In critical circumstances, such confusion can lead to a hazardous situation or at least make it difficult for the crew to respond in an appropriate manner.

The HF team recommends flightcrews be trained in the underlying principles of the system's design leaving some of the details to individual good operating practice or technique. Based on the HF report, the FAA should provide clear and concise guidance on:

- Examples of circumstances in which the autopilot should be engaged, disengaged, or used in a mode with greater or lesser authority;
- The conditions under which the autopilot or autothrottle will or will not engage, will disengage, or will revert to another mode; and
- Appropriate combinations of automatic and manual flight path control (e.g., autothrottle engaged with the autopilot off).

While most of this information may be found scattered throughout several training volumes, the HF team recommended clear and concise guidance to promote better flightcrew understanding of the capabilities and limitations of the automation. Where possible this guidance should include practical demonstrations of use during training. Practical examples are intended to demonstrate particular cases where safety can be improved by appropriate automation choices.

Pilot Decisions

The team found that "flightcrews differ in use of automation when responding to an abnormal situation, and more importantly, crews may react in ways not foreseen or taken into account during the design, certification, training, and procedure development for highly automated airplanes" (Abbott, 1996, p. 34). Observations by the HF team include situations where crews have either inappropriately continued to use the automation when in an abnormal situation or, if the automation was initially off, turned the automation on to try to accomplish a recovery. The report included specific examples:

- Fixation on following the flight director and ignoring airplane attitude. In one particular case, this resulted in a low speed excursion, after which the flightcrew engaged the autopilot to accomplish the recovery.
- Using the autopilot to recover from an overspeed warning rather than resorting to manual control.

- Attempts by the flightcrew to engage the autopilot in the moments preceding the March, 1995, crash of a Tarom A310 at Bucharest as they attempted to recover from an extreme bank angle resulting from a large thrust asymmetry.
- Engagement of the autopilot by the flightcrew of the A300-600 that crashed at Nagoya, Japan in April, 1994 -- apparently in response to difficulties in maintaining the glide slope following the inadvertent activation of the takeoff/go-around levers.

The team hypothesized that the action of engaging the autopilot to attempt to recover an unrecognized situation shows that flightcrews are becoming less confident in their own airmanship skills relative to the capabilities they perceive to be present in the automation, particularly in a stressful situation. In some cases, where this perception of the automation's capabilities is particularly inaccurate, it can have potentially hazardous consequences.

The FAA report noted weaknesses in several areas relative to current practices for developing and implementing standard operating procedures. Since a strong link exists between procedural deficiencies and airplane accidents it is important to address this issue. The HF Team noted particular concern about the following types of procedures:

- Procedures used by operators that are inconsistent or conflict with the airplane manufacturer's design philosophy and recommended procedures (e.g., not using autobrakes, flight directors, or other systems/features as designed);
- Procedures that are used as a work-around for design deficiencies (e.g., flightcrew call-out of mode changes as a primary means for providing mode awareness; forbidding programming the FMS below a certain altitude);
- Procedures that are not covered adequately in training (e.g., use of FMS vertical flight path modes);
- Procedures or procedural steps that do not promote understanding of the action(s) that the flightcrew are to undertake, especially for procedural items that do not appear to be directly related to the desired objective (e.g., consequences of activating or not activating the approach mode on certain FMS systems and the use of FMS one-engine-inoperative driftdown procedures);
- Incomplete consideration of the potential for errors and the resulting hazards, especially when using the procedures under varying circumstances (e.g., inappropriate use of the open descent mode at low altitude, changing FMS arrival

runway information, and inadvertent deletion of intermediate route or altitude constraints);

- Procedures carried over from one airplane type to another for standardization purposes, but could have unintended consequences or are otherwise inappropriate for the different airplane type (e.g., not using autobrake capability for rejected takeoffs or not using flight director information when it is readily available and suitable for the task).

Summarizing the HF Team report, the aviation system is safe, but vulnerabilities in the flightcrew/automation interface exist, especially in the area of flightcrew management of automation and situation awareness. These vulnerabilities appeared to exist to varying degrees across the current fleet of transport category airplanes, regardless of the manufacturer, the operator, or whether accidents have occurred in a particular airplane type.

The 1996 FAA Human Factors report contributes recommendations that expand on the philosophy of human-centered aviation developed by Dr. Billings. The FAA and aircraft designers and operators would be wise to adopt these recommendations. Today, the three main aircraft producers, Airbus, Boeing, and McDonnell Douglas, possess three different design philosophies. Two of these philosophies are similar to each other, but one, Airbus, is very different.

Airbus Philosophy

Airbus Industrie officials believe that if the technology exists to automate a function that would prevent a pilot from inadvertently exceeding safety limits, this should be done (Hughes, et. al, Jan, 1995, p.54). Airbus' design philosophy on file with the FAA is:

- Automation must not reduce overall aircraft reliability; it should enhance aircraft and systems safety, efficiency and economy.
- Automation must not lead the aircraft out of the safe flight envelope and it should maintain the aircraft within the normal flight envelope.
- Automation should allow the operator to use the safe flight envelope to its full extent, should this be necessary due to extraordinary circumstances.
- Within the normal flight envelope, the automation must not work against operator inputs, except when absolutely necessary for safety. (Bluecoat newsgroup, 1997)

Airbus fly-by-wire aircraft have "hard" speed envelope protection features. An Alpha floor function prevents a pilot from stalling the Airbus. When a maximum angle of attack is reached, the autothrottle system will automatically select go-around power and command a pitch down, regardless of pilot inputs. This uncommanded, and often unexpected maneuver has resulted in at least two crashes in France, an A320 flyover demonstration in Habsheim, and an A330 test flight at Toulouse (Billings, 1996). A second "hard" envelope limits the pilot to no more than 2.5g in any circumstances, even an emergency. This is a concern to some pilots who fly these aircraft. One never knows when the situation will exist that the difference between the 2.5g limit and the 3.0g needed could be the difference between hitting the other aircraft/mountain and popping a few rivets loose in an avoidance maneuver. Further, the Airbus A320 has independent side-stick controllers and throttles that don't move when the autothrottle system is engaged. The independent side stick controllers further impede one pilot from observing direct aircraft inputs of the other pilot. Dr. Charles Billings has reported that this lack of tactile feedback on A320 control systems has evoked "fairly widespread concern" in the industry (Hughes, et. al, 1992, p. 51). Pilots prefer to be kept informed of what the aircraft is doing and to let decision processes be left to them, not the engineers in a laboratory.

Some researchers and pilots believe that some Airbus systems are over-automated. Previous discussions about accidents/incidents in this paper point to examples of these claims. An experienced pilot commented that the A320 cockpit design tends to isolate the pilot from the control loop, providing insufficient feedback and stimulating an inappropriate sense of security (Bluecoat Newsgroup, 1997). Based on conversations with many other pilots, he is not alone.

However, Pierre Baud, Airbus Industrie senior vice president-training, contends "Airbus transport glass cockpits are not over-automated; we only proved to be more imaginative [than the competition] in applying available technology" (Hughes, et. al, Jan, 1995, p. 62). Bernard Ziegler, Airbus senior vice president of engineering, attributed the Nagoya, Japan A300-600 accident and the A310 incident in Moscow to the flight crew fighting against the autopilot (Hughes, et. al, Jan, 1995, p. 53). Ziegler claimed that Airbus never expected both the pilot and autopilot to be flying the airplane at the same time. If the pilot is not satisfied with what the autopilot is doing, Ziegler expects the pilot to disconnect the autopilot and fly manually.

Boeing Philosophy

Boeing has a different philosophy that automation is a tool to aid pilots and should not be given authority to override pilot inputs. As stated to the FAA, Boeing's philosophy on automation is:

- The pilot is the final authority for the operation of the airplane.
- Both crew members are ultimately responsible for the safe conduct of the flight.
- Flight crew tasks, in order of priority, are: safety, passenger comfort, and efficiency.

- Design for crew operations based on pilot's past training and operational experience.
- Design systems to be error tolerant.
- The hierarchy of design alternatives is: simplicity, redundancy, and automation.
- Apply automation as a tool to aid, not replace, the pilot.
- Address fundamental human strengths, limitations, and individual differences - for both normal and non-normal operations.
- Use new technologies and functional capabilities only when:
  - * They result in clear and distinct operational or efficiency advantages, and
  - * There is no adverse effect to the human-machine interface.
  (Bluecoat Newsgroup, 1997)

This philosophy is adhered to in the newest Boeing aircraft, the 777. The 777 incorporates a "soft" protection system which requires the pilot to apply more force on the control yoke when exceeding 35° of bank and when pulling the yoke back as the aircraft decelerates below minimum maneuver speed (Hughes, et. al, Jan, 1995, p.54). The changing control input requirements warn the pilot of a high bank angle or an approach to stall, but the pilot still has access to the full performance envelope if needed.

McDonnell Douglas Philosophy

The McDonnell Douglas philosophy of automating the MD-11 is, if it can be automated, automate it, but keep the crew informed and maintain the ability for the pilots to take over manually if they so desire (Hughes, et. al, 1992, p. 58). By keeping the pilot in the loop, Douglas engineers ensured pilot situational awareness. McDonnell Douglas has a very simple philosophy on file with the FAA: "Use technology to assist the pilot naturally, while giving the pilot the final authority to override the computer and use skill and experience" (Bluecoat Newsgroup, 1997).

A "soft" protection system similar to that of Boeing is found on the MD-11. However, the MD-11 design gives a large amount of authority to automatic controllers that manage the fuel, electrical, hydraulic and pneumatic systems. These systems are usually run by two computers which automatically troubleshoot and reconfigure the systems to restore as much of the functions as possible (Hughes, et. al, 1992, p. 58). Pilots have expressed a preference for the intuitive format of the MD-11 systems displays.

C-17 Design Philosophy

The C-17 is a McDonnell Douglas product and is similar in design philosophy to the MD-11. However, according to Bill Casey, C-17 chief pilot for McDonnell Douglas, the company intentionally diverged from the commercial cockpit designs to resolve concerns about the lower experience levels of military pilots compared to civilian, and the requirement to fly more complicated missions, including combat (Hughes, et. al, Feb, 1995, p. 54). Also, although the C-17 is a very new aircraft, the initial design specifications were completed nearly 25 years ago. When in the design phase, the plans utilized front-line technology. However, political and financial constraints delayed the program, and when the C-17 finally made it through production, the front-line technologies of 1978 were antiquated. The cockpit displays are a clear example of this, the C-17 has cathode ray tubes, compared with active matrix liquid crystal displays in the Boeing 777 and more recently designed aircraft (Hughes, et. al, Jan, 1995, p. 54).

Casey's view is that the civil world automates all the standard functions and the pilots exercise management by exception. Instead of automated high technology, the C-17 used the Lincoln Logs, or a simplified, "dumb" cockpit approach (Hughes, et. al, Feb, 1995, p. 54). In this approach Casey says, "if you don't know what it does, don't touch it, and it won't do anything." This philosophy permits sequential learning. The automation functions are easy for an inexperienced pilot to learn quickly, and as the pilot gains more experience and becomes more comfortable, he can gradually take on the more advanced capabilities. The down side to this philosophy, and a conscious trade-off by the military, is that an expert in the C-17 cockpit will have to push more buttons to command a specific action than his airline counterpart (Hughes, et. al, Feb, 1995, p. 54).

IV. Operations Philosophies

Some airlines procure aircraft from only one manufacturer, but most airlines fly a variety of aircraft from different manufacturers based on the capacity criteria of the route that the aircraft will service. Different design philosophies have resulted in pilots encountering problems transitioning from one aircraft manufacturer to another. For example, the autopilot disconnect systems in the Airbus A300 and A310 are significantly different than the disconnect systems provided in other large transport-category airplanes (Hughes, et. al, Jan, 1995, p. 60). This difference may have contributed to the loss of the A300 in Nagoya, Japan in 1991. The Flight Data Recorder (FDR) showed the pilot had manually intervened to counter the autopilot. This action in a Boeing or McDonnell Douglas type aircraft would have disconnected the autopilot, but in the A300, the autopilot remains engaged. Further, the autopilot countered the inputs of the pilot, eventually resulting in loss of aircraft control. Appendix 1 contains the Nagoya accident as well as other examples of automation incidents/accidents.

One constraint to an airlines operating philosophy is company executives, who spend millions of dollars obtaining these expensive aircraft, expect to reap a benefit from their purchase. This expectation sometimes trickles down to the line crewmember as a philosophy of we bought it, you have to use it. Many airlines are avoiding this potential problem by developing formal automation philosophies for pilots. The following companies already have published automation philosophies.

Delta

Delta Airlines was one of the first major airlines to publish a corporate automation policy. Chapter 4 of the Delta flight operations manual states:

> Automation is provided to enhance safety, reduce pilot workload and improve operational capabilities. Automation should be used at the most appropriate level. Pilots will maintain proficiency in the use of all levels of automation and the skill required to shift between levels of automation. The level used should permit both pilots to maintain a comfortable workload distribution and maintain situational awareness. (Bluecoat Newsgroup, 1997)

The following guidelines apply to the use of automation at Delta Airlines:

- If any autoflight system is not operating as expected, disengage it.
- All pilots should be aware of all settings and changes to automation systems.
- Automation tasks should not interfere with outside vigilance.
- Briefings should include special automation duties and responsibilities.
- The pilot flying (PF) must compare the performance of the autoflight systems with the flight path of the aircraft.
- When a pilot conducts a briefing, the level of automation will be addressed. (Bluecoat Newsgroup, 1997)

Delta provides a four-hour course called introduction to automated aircraft (IA2) to all pilots that transition to glass cockpit aircraft. The class teaches this automation philosophy and includes accident and incident discussions related to automation.

Cathay Pacific Airways

Cathay Pacific Airways (CPA) has been operating for 51 years as a private airline based in Hong Kong. CPA has over 60 widebody aircraft, 1400 cockpit crew, 4500 cabin crew, and 15,000 employees. CPA insists that pilots not feel pressured to use automation at all times. This airline found it advantageous to provide a clear policy to crews:

> It is the Cathay Pacific Airways (CPA) Policy to regard automation as a tool to be used, but not blindly relied upon. At all times, flight crew must be aware of what automation is doing, and if not understood or not requested, reversion to basic modes of operation should be made immediately without analysis or delay. Trainers must

> ensure that all CPA Flight Crew are taught with emphasis on how to quickly revert to basic modes when necessary. In the man-machine interface, man is still in charge. (Bluecoat Newsgroup, 1997)

Cathay Pacific Airways believes if trainees are provided the designer's philosophy, preconceived mind sets can be overcome and knowledge can be acquired faster. Pilots are generally inquisitive and want to know as much about a system as possible. CPA attempts to satisfy this curiosity by answering the question why? CPA provides a video to new trainees which features a design test pilot's complete explanation for the automation used (CRM Developers Group, 1997).

United

In 1995 United Airlines revised its pilot training philosophy to a consistent, mission-oriented approach that tends to be more compatible with highly automated aircraft (Hughes, et. al, Feb, 95, p. 50). United has taken the approach that pilots don't need to know the systems as well as they had in the past. Since most aircraft today automatically diagnose and correct malfunctions, then inform the pilot of the system's status, United believes that good systems knowledge is unnecessary for pilots. United stresses cockpit discipline and following rigid standard operating procedures (SOPs). These SOPs include announcing changes in the status of the autopilot and system modes. United aims at teaching interfacing with the aircraft systems through the Flight Management System (FMS).

S. William Reichert, United's manager of fleet operations for the A320, and B737-200 through 400 series, says that the key to automation is awareness. He states that operating these aircraft is more a matter of systems management than actually flying the aircraft (Hughes et. al, Feb, 1995, p. 51). United's pilots are trained to follow handbook operations, and would-be systems experts are discouraged from taking nonstandard actions. This philosophy is different from the military philosophy of understanding intricately how the system works so you are better prepared to react to fix any problems that may occur that might not be in the flight manual.

C-17 Operating Philosophy

The C-17 Operations are guided by Multi Command Instruction (MCI) 11-217. Section A, General Operating Policies provides the following guidance as the official philosophy of the Air Force toward operating the C-17:

> The C-17A is designed to be operated by three crew members, two pilots and one loadmaster. In order to perform the same demanding worldwide strategic and theater missions currently flown with larger crews, automation is employed. All technical orders, procedures, checklists, training, and supporting documents are designed to support the human operator. It is the responsibility of the crew to fully understand the operations and limitations of the automation on the aircraft. In flight, the pilot flying (PF) will determine the most desirable level of automation for a given situation. (MCI 11-217, p. 2)

MCI 11-217 also provides the following operating guidelines:

- The aircraft commander (AC) has the ultimate responsibility and authority for the safety of the aircraft, passengers, and crew.
- The AC must manage workload, set priorities and employ the available resources, including automation, to maintain overall situational awareness.
- Us appropriate levels of automation as required by the flight conditions. As the flight situation changes, do not feel locked into a level of automation.

The Instruction also points out the following common pitfalls associated with over-reliance, misuse, or misunderstanding of automation:

- Fixating on the automation
- Misprioritizing programming tasks
- Mode Awareness
- Assuming automation is programmed correctly.
- Over-reliance on automation

In addition, the instruction provides a discussion about standard terminology for operating the Automatic Flight Control System (AFCS), including examples of commands and recommended abbreviations.

In general, the Air Force expects the C-17 aircrew to let the aircraft perform automatically to the maximum extent possible. The Air Force believes this will decrease the workload of the pilots, allowing them to manage the mission more effectively.

V. Automation Pitfalls

Aircraft designers attempt to anticipate difficulties and dangers associated with the aircraft and incorporate solutions into the design. If they are unsuccessful, the operators of the aircraft will include a warning or caution to avoid the known hazard. However, with all systems there are intrinsic dangers, or pitfalls, that the operator must remain cognizant of, and make an every effort to avoid. This section of the paper identifies pitfalls associated with automated aircraft that all operators should seek to avoid.

In two series of questions conducted four years apart, Capt Harry W. Orlady, a retired United Air Lines pilot, sought to identify some of the controversies associated with the "glass cockpit." He identified a number of controversies among pilots:

1) The real-life workload that exists under normal, abnormal and emergency conditions
2) The role of the pilot in these new aircraft, including maintenance of the captain's authority
3) The existence and, much more important, the operational consequences of fatigue, boredom and complacency that might be caused by these aircraft. (Orlady, 1992)

Workload

One of the stated promises of incorporating automation into the cockpit is that it will decrease pilot workload and allow more time for decision making. After more than a decade of experience, this promise is still largely unfulfilled. Earl L. Wiener, professor of management science at the University of Miami, surveyed 200 line pilots from two airlines flying Boeing 757 aircraft. While the majority of pilots expressed pride in flying the most advanced aircraft in their company's fleet, at least half said they felt automation actually increases workload and, one year later, these pilots showed no shift in their opinion.

While some believe automation may have reduced pilot workload, studies show automation may have merely redistributed workload (Hughes, et. al, 1992, p. 67). For example, pilots of older aircraft are manually tasked to operate the controls as they fly, while they are cognitively tasked to communicate, process information and make a decision. The pilots of newer, automated aircraft, performing the same functions, are more cognitively tasked to receive information, identify and then input that information into the appropriate FMS sub-menu and engage the automation to perform the desired task. Depending on how workload is measured, either one of these situations could be determined to be more or less intensive than the other. The former manual process clearly is more physically demanding, but the latter example of determining which sub-menu is appropriate for the function being accomplished, finding it, and inputting the appropriate information is significantly more cognitively demanding. Degani and Wiener found high, manual workload associated with fatigue and the monitoring of automatic systems responsible for complacency and boredom. This continuum is graphically depicted in Figure 3.

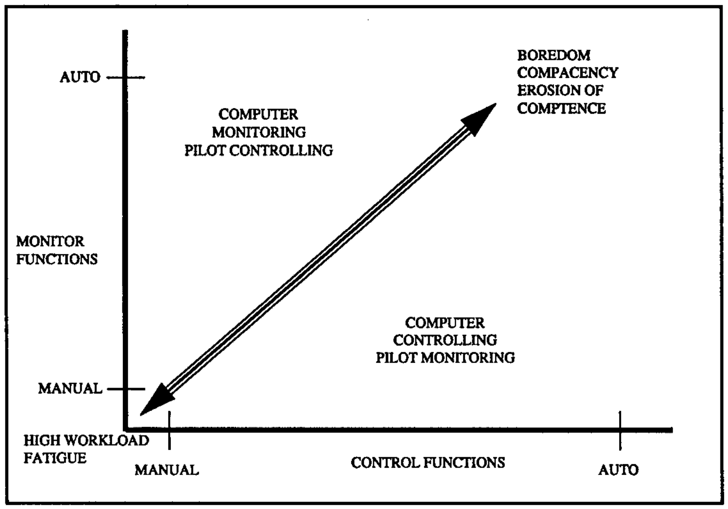

Figure 3: Monitor and Control Functions Across the Workload Continuum (Billings, 1996, p. 183)

Current research has actually identified an increase of pilot workload. Degani and Wiener found that most workload reductions occur when work levels were already low, such as during cruise (Billings, 1996, p. 139). The many changes experienced during the historically high workload situations, such as departure and arrival, can actually increase crew activity in highly automated aircraft. Because pilots are forced to focus their attention inside the aircraft to perform these changes they are not able to look outside for possible conflicts.

Captain's Role

The traditional role of Captain being in command of his aircraft is challenged by automation. As discussed previously (see Figure 2) the increase in technology over the years has distanced pilots from actual control of their environment. Also, the sometimes laborious FMS entries require that the pilot not flying (PNF), usually the first officer, make changes to the flight profile, while the pilot flying (captain) monitors the aircraft. By ultimately affecting the course of the aircraft the PNF, in essence, becomes the PF.

This shared control of the aircraft weakens and blends established cockpit roles and may lead to confusion about who is actually in control of the aircraft.

Pilots can play any of a variety of roles in the control and management of a highly automated airplane. These roles range from direct manual control of flight path and aircraft systems to a largely autonomous operation in which the pilot's active role is minimal. This allocation of functions is represented in the following control-management continuum (Table 1) by Dr. Charles Billings:

Table 1: The Control/Management Continuum for Pilots (Billings, 1996, p. 104)

VERY LOW ← LEVEL OF AUTOMATION → VERY HIGH

Management Mode	Automation Functions	Human Functions
Autonomous Operation	Fully autonomous operation Pilot not usually informed System may or may not be capable of being disabled	Pilot generally has no role inoperating Monitoring is limited to fault detection Goals are self-defined; pilot normally has no reason to intervene
Management By Exception	Essentially autonomous operation Automatic reconfiguration System informs pilot and monitors responses	Pilot informed of system intent; Must consent to critical decisions; May intervene by reverting to lower level of management
Management By Consent	Full automatic control of aircraft and flight Intent, diagnostic and prompting functions provided	Pilot must consent to state changes, checklist execution, anomaly resolution; Manual execution of critical actions
Shared Control	Enhanced control and guidance; Smart advisory systems; Potential flight path and other predictor displays	Pilot in control through CWS or envelope-protected system; May utilize advisory systems; System management manual
Assisted Manual Control	Flight director, FMS, nav modules; Data link with manual mesages; Monitoring of flight path control and aircraft systems	Direct authority over all systems; Manual control, aided by F/D and enhanced navigation displays; FMS is availabe; trend info on request
Direct Manual Control	Normal warnings and alerts' Voice communication with ATC; Routine ACARS communications performed automatically	Direct authority over all systems; Manual control utilizing raw data; Unaided decision-making; Manual communications

VERY LOW ← LEVEL OF INVOLVEMENT → VERY HIGH

A pilot must be able to operate the aircraft as necessary for safe flight. As previously discussed, Airbus A320 designers have limited the amount of direct control, preventing manual inputs that exceed pre-determined parameters. The A320 is only one example where designers have limited the pilots operating parameters from the design bench.

Complacency

Crew complacency is often mentioned as one potential negative effect of automation. The theory is that as pilots perform duties as systems monitors they will be lulled into complacency, lose situational awareness, and not be prepared to react in a timely manner when the system fails. Wiener (1981) defined complacency as "a psychological state characterized by a low index of suspicion." In the NASA Aviation Safety Reporting System (ASRS) coding manual, complacency is defined as "self-satisfaction which may result in non-vigilance based on an unjustified assumption of satisfactory system state" (Parasuraman, et. al, 1993).

Parasuraman, Molloy, and Singh (1993) indicated that the major factors contributing to "complacency potential" were a person's trust in, reliance on, and confidence in automation. Crew attitudes such as overconfidence in automation may not be sufficient in themselves to lead to complacency but may only indicate a potential for complacency. Parasuraman, Molloy and Singh propose that complacent behavior may arise only when complacency potential occurs jointly with other conditions such as high workload brought about by poor weather, heavy traffic, or fatigue due to poor sleep or long flights. The combination of the crew's attitude toward automation (e.g., overreliance) and a particular situation (e.g., fatigue) may lead to complacent behavior.

The dominant tendency of technology-centered design has been to reduce pilot workload and to reap the benefits of economies such as fuel efficiency and reduced manning costs. The study by Parasuraman, Molloy and Singh supported the position that taking the pilot out of the loop by automating a function degrades system awareness and manual skills, so that the pilot may not be able to intervene effectively if the automation fails. The results of this study again add support to Dr. Billings' Human-Centered design philosophy.

Mode Confusion

A flight management system (FMS) on an advanced aircraft is capable of conducting an entire flight without the pilot flying the plane. To do this the flight modes will automatically transition from climb, to level off, cruise, descent and finally approach. Each one of these modes provides different input characteristics to the aircraft, and the pilot must always be aware of the operating mode to remain prepared to return to manual flight. In some aircraft, keeping informed of this mode change requires monitoring a very small display on the glareshield of the aircraft. It is easy to see at night, but can be very difficult to monitor in daylight, especially if the sun is directly on the glareshield. If the pilot takes command of the aircraft manually and assumes the aircraft to be in a particular mode and it is not, the result could be disastrous. The Airbus A300 crash in Nagoya, Japan, is an example of the pilot taking manual control of the aircraft when the aircraft was on an approach. The pilot inadvertently activated the go-around mode, which on the A300 commands full power and a rapid climb away from the ground. The pilot attempted to continue the approach manually and fought against the autopilot, causing the pitch trim to run to the limit. The aircraft became uncontrollable and crashed.

A major area of concern with the rapid development of cockpit systems is that technology has outpaced human ability to fully comprehend automated mode behaviors (Hughes, et al., Jan, 1995, p. 63). Barry Strauch, Chief, Human Factors Division at the

National Transportation and Safety Board (NTSB), stated in 1995 that "pilot awareness and understanding of computer modes in modern transport aircraft is a problem" (Hughes, et. al, Jan, 1995, p. 63). A study of mode confusion was conducted by the Massachusetts Institute of Technology (MIT) in 1994. The Aviation Safety Reporting System (ASRS) was searched for incidents related to mode confusion. The MIT team identified 184 incidents of mode awareness problems and broke them down into six categories (Hughes, et. al, Jan, p. 56). The six categories are shown in Figure 4 and described in Table 2.

The MIT study found that 74% of the incidents involved confusion or errors in vertical navigation, while 26% were problems related to horizontal, or lateral, navigation. R. John Hansman, an MIT professor, noted that newer aircraft provide better feedback on horizontal navigation than vertical. Most advanced aircraft are equipped with a display that overlays an electronic map of the aircraft route, including land based navigational aids, with the weather. This display provides a clear picture to the pilot of where the aircraft is going and how it will proceed. By contrast, no such picture exists for vertical navigation so the pilot must develop a mental model of how vertical navigation is affecting the flight path.

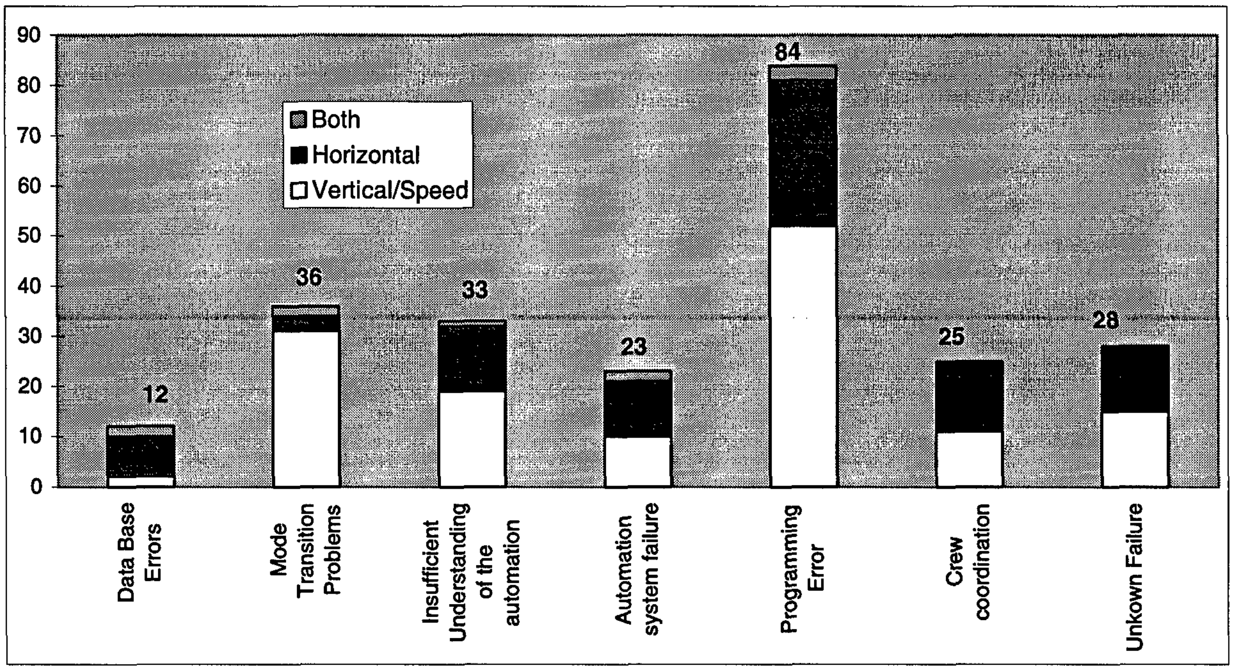

Figure 4: Mode Awareness Incidents (Hughes, et. al, Jan, 1995, p. 56)

Table 2: Discussion of Error Categories from Mode Awareness Study (Hughes, et. al, Jan, 1995, p. 56)

Data Base Error	A FMS data base error caused the crew to either execute an incorrect procedure, or to question the validity of the automatic flight system (AFS) commands.
Mode Transition problem	Flight crew confusion or aircraft deviation because the AFS executed an unexpected mode transition, or failed to execute an expected mode transition.
Insufficient understanding of the automation	Because one or more of the crew members did not fully understand the consequences of an action or inaction, confusion or a deviation occurred.
Programming error	A partial or full AFS failure that resulted in crew confusion or an aircraft deviation.
Crew coordination	Incorrect data input or mode selector that was not identified immediately and resulted in an unexpected mode, mode change or deviation.
Unknown Failure	Any sequence of events initiated by one crew member that caused one or more of the other crew members to incorrectly assume a mode, mode transition or parameter.

Hansman pointed out that vertical navigation is difficult to comprehend because it involves the use of different combinations of elevator and thrust inputs. Automated systems are capable of maintaining an air speed, a vertical speed, or a flight path angle, in the climb. Each possibility affects the vertical flight path in a different manner.

To preclude mode confusion, Barry A. Strauch of the NTSB advocates a more stringent pilot selection process coupled with advanced training standards that fully expose pilots to the complex capabilities of current and future glass cockpits (Hughes, et al, Jan, 1995, p. 63). In summary, Earl Wiener points out that although a key function of cockpit automation has been to help eliminate mistakes, "it is a fallacy to think that automation removes human error when it actually can give the pilot opportunities to make even larger mistakes" (Hughes, 1992). It is the goal of designers, operators and regulating agencies to minimize these opportunities for mistakes.

VI. Recommendations

This section of the paper expands upon the philosophy and policies represented in Multi-Command Instruction (MCI) 11-217 and makes recommendations that might be incorporated into future Air Force instructions. These recommendations are based on the FAA Human Factors (HF) Team Report, Interfaces Between Flightcrews and Modern Flight Deck Systems (Abbott, 1996). These recommendations are adapted for the unique characteristics of the military mission.

The Air Mobility Command provides an excellent operating policy to its crews. This policy, found in MCI 11-217, Volume 5, is already in line with many recommendations from the HF team report. The HF team recommends "that a uniform set of information regarding the manufacturer and operator philosophies about automation be explicitly conveyed to flightcrews." This information should include but not be limited to:

- The manufacturer's higher level design philosophy (e.g., the reasons for automating particular functions) to the extent that this philosophy could affect operational use;
- The operator's automation philosophy, which should be used as the basis for operator policies, procedures, and practices related to automation use;
- The principles of operation (e.g., operating assumptions used in the design, such as the basis for the computation of vertical flight profiles);
- A description of the envelope protection features, including specific capabilities and limitations, and the situations or flight conditions for which envelope protection is or is not available;
- Guidance (including rationale) relative to selecting the appropriate level of automation for routine use and non-routine situations (e.g., when confused by automation response, engine failure in different phases of flight, unusual attitudes, speed excursions (high or low), terrain or collision avoidance, flight path deviations, or unexpected or difficult air traffic clearances or requests);

- Standard operating procedures should be consistent with the operator's automation philosophy for each airplane type and should promote understanding of the action(s) expected of the flightcrew and the automation.

Although the Air Force provides much information in initial training and MCI 11-217, the Air Force should work to provide better information to crews about the appropriate levels of automation for routine and non-routine use. Further, the Air Force should establish standard design guidelines for future generation of flight management systems. This practice would minimize the effect of transitioning from one airframe to another. The HF report recommends establishing industry guidelines for FMS design in the following areas (Abbott, 1996, p. 40):

- Standardization of route, leg, and constraint conventions such as waypoint entry conventions, definition, and implementation of vertical profiles (e.g., vertical navigation), etc. to reduce error potential and facilitate an easier transition between airplane types or derivatives;
- Critical or irrevocable entries should be confirmed before they are executed, as well as providing an "undo" capability when appropriate;
- Response time should be improved when long response times can lead to flightcrew distraction from other essential tasks or cause programming errors;
- Titles of pages and relationships among different pages should be clear and unambiguous so as to facilitate easy access to information;
- Unanticipated dropping of information (e.g., waypoint, altitude constraints) should be addressed when it leads to frequent incorrect path definition or excessive workload in using "workarounds;"
- Error messages should be meaningful and helpful (e.g., in response to improper entry) and assist the flightcrew in correcting the entry (e.g., "invalid entry" is insufficient, instead provide the appropriate format to use or identify the missing information).

Standardization at this point for civil aviation would be both expensive and time consuming due to the significant number of airframe designs already in existence. However, since the Air Force is just entering into the advanced aircraft arena, this is an excellent opportunity to establish standards for future design that will facilitate development.

Conclusion

While at the NASA Ames Research Center, Dr. Charles Billings said, "Automation is there to use, but it must be as simple to manage as the aircraft is to fly" (Orlady, 1992). This seems to be the root of current problems in aviation. Unfortunately, early automation was implemented in the cockpit on the implicit assumption that machines could be substituted for humans. The theory of "if it can be automated, do it" pervaded the industry. In the past ten years we have seen the limitations of this theory; the pilot becomes increasingly removed from the operation of the aircraft.

This paper provided a discussion of automation and presented philosophies that exist in the aviation industry today. Whether it is a cultural or economic coincidence or with forethought and intention, the automation philosophy of the European consortium, Airbus, is significantly different from that of American airline manufacturers. The result is different courses of action and different cognitive processing of what each aircraft will or will not do automatically. Obviously these significant differences can result in serious consequences when moving from one aircraft type to another. This is an important concept for the Air Force to embody; today the Air Force is in the process of purchasing a second advanced cockpit transport aircraft, the Lockheed C-130J, from a different manufacturer than the C-17. It is logical to assume that individuals qualified in one airframe may eventually transition to the other. If both aircraft operate on similar philosophies then that transition will be made easier and faster. The shorter training period will result in lower training costs to the Air Force.

The philosophies of civilian airline companies presented in this paper were the only ones available to the author. Other airlines may publish philosophies, but only the stated few were willing or able to share their philosophies. The Air Force should stay informed of civilian philosophies and further develop current philosophies to enhance flightcrew understanding and facilitate development of future designs. The FAA Human Factors Team recommends that all operators and designers establish automation philosophies in a formal statement. By stating the philosophy, operators and designers provide a valuable foundation for flightcrews to understand the automation. A better understanding will facilitate operations and may avoid some of the incidents and accidents described in Appendix A of this report. By establishing a philosophy of its own, the Air Force is well on its way to continued success with the C-17 and future aircraft designs.

Appendix A : Automation Incidents and Accidents

Date	Location	Airplane Type	Operator	Description
12/29/72	Miami	L-1011	Eastern Air Lines	Flightcrew members became immersed in an apparently malfunctioning landing gear. Airplane was in control wheel steering mode. Altitude hold inadvertently disengaged by a light force on the control wheel. Altitude alert aural warning not heard by flightcrew. Fatal crash.
7/31/73	Boston	DC-9-31	Delta Air Lines	Airplane landed short during an approach in fog. Flightcrew was preoccupied with questionable information presented by the flight director. Fatal crash.
2/28/84	New York	DC-10-30	Scandin-avian Airlines	Malfunctioning autothrottle system during approach resulted in crossing the runway threshold at 50 knots above reference speed. Runway was wet, touchdown was 4700 feet beyond the threshold of an 8400 foot runway. Airplane overran runway, minor injuries. Complacency and over-reliance on automatic systems cited.
2/19/85	San Francisco	747SP	China Airlines	Loss of power on one engine during autoflight. Autopilot tried to compensate until control limits were reached. Captain disengaged autopilot, airplane went into unusual attitude high speed dive, but was successfully recovered. Autopilot masked approaching onset of loss of control.

Date	Location	Airplane Type	Operator	Description
6/26/88	Habsheim	A320	Air France	Low, slow flyover at air show. Ran out of energy and flew into trees. Possible overconfidence in the envelope protection features of the A320. Fatal crash.
7/3/88	Gatwick	A320	unknown	Programmed for 3 degree flight path, but inadvertently was in vertical speed mode, almost landed 3 miles short.
1/89	Helsinki	A300	KAR Air	While making an ILS approach, the takeoff/go-around lever was inadvertently depressed. In response to the unexpected and sudden nose-up change in the airplane's attitude, the flightcrew immediately reacted by re-trimming.
6/8/89	Boston	767	unknown	On autopilot ILS approach, airplane overshot the localizer. Captain switched from approach to heading select mode to regain the localizer , disengaged the autopilot, and used the flight director. Since the glide slope had not been captured, the flight director was in vertical speed mode commanding an 1,800 fpm rate of descent. Alert from the ground proximity warning and tower resulted in a go-around from about 500 feet.
2/14/90	Bangalore	A320	Indian Airlines	Inappropriate use of open descent mode. Fatal crash.
6/90	San Diego	A320	unknown	Pilot mistakenly set vertical speed of 3,000 fpm instead of 3.0 degree flight path angle. Error was caught, but airplane descended well below profile and minimum descent altitude.

Date	Location	Airplane Type	Operator	Description
2/11/91	Moscow	A310	Interflug	Pilot intervention in auto-pilot coupled go-around resulted in the autopilot commanding nose-up trim while the pilot was applying nose-down elevator. Autopilot disconnected when mode transitioned to altitude acquire mode - force disconnect not inhibited in this mode as it is in go-around mode. Airplane ended up badly out of trim and went through several extreme pitch oscillations before the flightcrew regained control.
1/20/92	Strasbourg	A320	Air Inter	Evidence suggests flightcrew inadvertently selected 3,300 fpm descent rate on approach instead of 3.3 degree flight path angle. Fatal crash.
9/14/93	Warsaw	A320	Lufthansa	Wet runway, high tailwinds -- After touchdown, the air/ground logic did not indicate the airplane was on the ground, and delayed deployment of ground spoilers and reversers. Airplane overran runway. Two fatalities.

Date	Location	Airplane Type	Operator	Description
9/13/93	Tahiti	747-400	Air France	VNAV approach with autothrottle engaged, autopilot disengaged. Upon reaching the published missed approach point, VNAV commanded a go-around and the autothrottle advanced power. After a delay, the flightcrew manually reduced power to idle and held the thrust levers in the idle position. The airplane landed long and fast. Two seconds prior to touchdown the number one engine thrust lever advanced to nearly full forward thrust and remained there until the airplane stopped. Reverse thrust was obtained on the other engines. The spoilers were not deployed -- the automatic system did not operate because the number one thrust lever was not at idle, and the flightcrew did not extend them manually. The flightcrew lost directional control of the airplane as the speed decreased and the airplane went off the right side of the runway.

Date	Location	Airplane Type	Operator	Description
6/6/94	Hong Kong	A320	Dragonair	After three missed approaches due to lateral oscillations in turbulent conditions, a landing was made and the airplane went off the side of the runway. The flaps locked at 40 degrees deflection (landing position) just before the first go-around due to asymmetry. Asymmetry caused by rigging at the design tolerance combined with gust loads experienced. In accordance with published procedures, flightcrew selected CONF 3 for landing, which extended slats to 22 degrees. With autopilot engaged, lateral control laws correspond to control lever position. Under manual control, control laws correspond to actual flap/slat position. The configuration CONF 3, with flaps locked at 40 degrees, is more susceptible to lateral oscillations with the autopilot engaged. After a similar incident in November, 1993, experienced by Indian Airlines, Airbus issued an Operations Engineering Bulletin to leave the control lever in CONF FULL if the flaps lock in that position.

Date	Location	Airplane Type	Operator	Description
4/26/94	Nagoya	A300-600	China Airlines	Flightcrew inadvertently activated the go-around switches on the throttle levers during a manually flown approach. This action engaged the autothrottles and put the flight guidance system in go-around mode. Flightcrew disconnected the autothrottles, but excess power caused divergence above the glide slope. Flightcrew attempted to stay on glide slope by commanding nose-down elevator. The autopilot was then engaged, which because it was still in go-around mode, commanded nose-up trim. Flightcrew attempted go-around after "alpha floor" protection was activated, but combination of out-of-trim condition, high engine thrust, and retracting the flaps too far led to a stall. Fatal crash.
6/21/94	Manchester	757-200	Britannia	Altitude capture mode activated shortly after takeoff, autothrottles reduced power, flight director commanded pitch-up before disappearing. Airspeed dropped toward V 2 before flightcrew pitched the nose down to recover.
6/30/94	Toulouse	A330	Airbus	Unexpected mode transition to altitude acquire mode during a simulated engine failure resulted in excessive pitch, loss of airspeed, and loss of control. Pitch attitude protection not provided in altitude acquire mode. Fatal crash.

Date	Location	Airplane Type	Operator	Description
9/24/94	Paris - Orly	A310-300	Tarom	Overshoot of flap placard speed during approach caused a mode transition to flight level change. Autothrottles increased power and trim went full nose-up for unknown reasons (autopilot not engaged). Flightcrew attempted to stay on path by commanding nose-down elevator, but could not counteract effect of stabilizer nose-up trim. Airplane stalled, but was recovered.
10/31/94	Roselawn	ATR-72	American Eagle	In a holding pattern, the airplane was exposed to a complex and severe icing environment, including droplet sizes much larger than those specified in the certification requirements for the airplane. During a descending turn immediately after the flaps were retracted, the ailerons suddenly deflected in the right-wing down direction, the autopilot disconnected, and the airplane entered an abrupt roll to the right. The flightcrew were unable to correct this roll before the airplane impacted the ground.

Date	Location	Airplane Type	Operator	Description
3/31/95	Bucharest	A310-300	Tarom	Shortly after takeoff in poor visibility and heavy snow, with autothrottles engaged, climb thrust was selected. The right engine throttle jammed and remained at takeoff thrust, while the left engine throttle slowly reduced to idle. The increasing thrust asymmetry resulted in an increasing left bank angle, which eventually reached about 170 degrees. The airplane lost altitude and impacted the ground at an 80-degree angle. Only small rudder and elevator deflections were made until seconds before impact, when the left throttle was brought back to idle to remove the thrust asymmetry. Fatal crash.
11/12/95	Bradley International Airport	MD-80	American Airlines	On a VOR-DME approach, the airplane descended below the minimum descent altitude, clipped some trees, and landed short of the runway. Contributing to this incident was a loss of situation awareness and terrain awareness by the flightcrew, lack of vertical guidance for the approach, and insufficient communication and coordination by the flightcrew.

Date	Location	Airplane Type	Operator	Description
12/20/95	Cali	757-200	American Airlines	Unexpectedly cleared for a direct approach to Cali, the flightcrew apparently lost situation awareness and crashed into a mountain north of the city. On approach, the flightcrew were requested to report over Tulua VOR. By the time this waypoint was input into the flight management computer, the airplane had already flown past it; the autopilot started a turn back to it. The flightcrew intervened, but the course changes put them on a collision course with a mountain. Although the ground proximity warning system alerted the flightcrew, and the flightcrew responded, they neglected to retract the speedbrakes and were unable to avoid hitting the mountain. Fatal crash.
2/6/96	Puerto Plata	757-200	Birgenair	After taking off from Puerto Plata, the flightcrew lost control of the airplane during climb and crashed into the ocean off the coast of the Dominican Republic. Problems with the captain's airspeed indication were encountered during the takeoff roll, and the takeoff and initial climbout were conducted using airspeed callouts by the first officer. Continued erroneous airspeed indications, possibly due to a blocked pitot tube, resulted in an overspeed warning during climb. Shortly thereafter the stickshaker activated. The conflicting warnings (overspeed and stall) apparently confused the flightcrew. The airplane entered a stall from which it did not recover. Fatal crash.

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Vita

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Major Valle is a Senior Pilot with over 3,500 flying hours in the C-141 and C-20 aircraft. His first assignment was to Charleston AFB, SC where he was qualified in the Air Refueling, Air Drop, and special operations missions in the C-141. Major Valle's second assignment was to Ramstein AB, Germany flying the C-20. During DESERT SHIELD/STORM Major Valle was deployed to Riyadh, Saudi Arabia as a C-20 pilot for CINCCENTCOM, General Norman Schwartzkopf. Major Valle's third assignment was to McGuire AFB, where he was the 305th Operations Group Chief of Standardization/Evaluation for the C-141. In January of 1996 he completed a degree of Human Factors in Aviation Systems Specialization from Embry-Riddle Aeronautical University. In February of 1996 he entered the Advanced Study of Air Mobility Program at Fort Dix, NJ. Following graduation in May 1997, Major Valle will be assigned to HQ USAF/XOOW, Plans and War Mobilization at the Pentagon, in Washington, D.C.

[redacted]

Automated Cockpit Technologies:
Implications for Air Mobility Command Aircrews

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This paper discusses automation philosophies of aircraft manufacturers and operators, including the philosophies employed in the McDonnell Douglas C-17 Globemaster III. Automation philosophy is defined and a human-centered automation philosophy advanced by Dr. Charles Billings is presented as the leading approach to future aircraft designs. Additionally, a discussion of some of the dangers and difficulties associated with the operation of automated aircraft are presented in an effort to enlighten Air Force aircrews of pitfalls associated with this new technology.

With the acquisition of the C-17 the Air Force has inaugurated a new generation of airlift aircraft. More than just replacing the C-141 as the workhorse of the Air Force, the C-17 has also replaced part of the crew with inertial navigation systems, computers, and automation. The reliance on the automation of the C-17 demands a smooth interface between crew and automation. This paper expounds on the existing philosophies found in Multi-Command Instruction (MCI) 11-217 and provides recommendations to future instructions. These recommendations are adapted from an FAA report discussing interfaces between flightcrews and modern flight decks. Finally, prior accidents and incidents associated with automation are presented in the appendix to the paper.